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Nikola Tesla, His Work and Unfulfilled Promises

By LAURENCE A. HAWKINS, E. E.

THAT commendation on the part of the public which we call fame is a prize struggled for throughout the world. It is as distinctly valuable as a mine, a 20-story building or any other property, and, in the estimation of many, great fame is of more value to its possessor than would be any section of mines or 20-story buildings. It is wise, then, on the part of society to see that this valuable thing, fame, is distributed justly.

Ten years ago, if public opinion in this country had been required to name the electrician of greatest promise, the answer without doubt would have been "Nikola Tesla." To-day his name provokes at best a regret that so great a promise should have been unfulfilled. In ten years the attitude of the scientific press has passed from admiring expectancy to good natured banter and at last to charitable silence. In 1892 a leading electrical periodical of this country contained the following ("Electrical World," Vol. 19, p. 20):

"During the past six months Mr. Nikola Tesla has been steadily at work developing the beautiful principles that he enunciated in his striking lecture before the American Institute of Electrical Engineers. In his skilful hands the experiments have extended far beyond their merely theoretical importance in the direction of important practical applications. The revolutionary character of his methods will make any extensive application of them of unique interest." In 1898, the same journal, speaking of Tesla's latest patented scheme, says ("Electrical World," Vol. 32, p 466): "Mr. Tesla, if correctly reported, previously proposed to wobble the earth's charge for man's ignoble uses, but he now, if these things can be taken seriously, has designs on the universe. The price of copper remains in the neighborhood of 11 cents, however." In 1900, a description of a Tesla patent which if practicable would revolutionize the electrical industry, is printed without one word of editorial comment. (" Electrical World," Vol. 35, p. 792.)

Tesla's career, since the time he first stepped into prominence by his lecture before the A. I. E. E. in 1888, naturally divides itself into three periods, which may be designated as the rotary field or patent period, the high voltage and high frequency or lecture period, and the present or newspaper period. It will be well to consider these separately in an endeavor to arrive at a just estimation of the man's work and of the value of his contributions to the engineering or scientific world.

Prior to 1884, the alternating current system of distribution, though older than the direct current system, was in little use. Gramme had taught the world how to build a satisfactory direct current commutator. Direct current seemed to have all the advantages of alternating current and would perform many services for which the latter was not suitable, notably electrolytic work. But in '83 and '84 Gaulard showed that the well known Ruhmkoff coil could be used to transform alternating current from high to low voltage, permitting of great economy in line wire, and he built and operated his transformer for lighting.

In 1885 Zipernowski & Deri produced a transformer of high commercial efficiency, and showed how to obtain excellent regulation, impossible with Gaulard's series system, by proper connection of the primaries in parallel. From this time alternating current began to be more used for electric lighting. One of the objections to the system was that there were no small self-starting motors that would operate efficiently on it. Accordingly, when Tesla announced, in May, 1888, that he had solved this motor problem, he at once became one of the most prominent figures in the engineering world. His solution was a theory of the combination of two or more alternating currents of different phase to produce a resultant rotating magnetic field. This same theory had been published in Italy a few weeks prior to Tesla by Ferraris. (" L'Elettricita," April 22, 1888.) Ferraris, however, contented himself with publication of the theory, while Tesla patented it, and followed up his first patents with a mass of other patents describing every conceivable construction and mode of operation that could in any way be imagined to embody his rotating magnetic field. It is for this reason that the rotating field theory is associated in this country with the name of Tesla rather than with that of Ferraris, although the contrary is the fact in every other country.

The idea of a rotating magnetic field as the resultant of two currents was not novel. It had been produced by Bailey (" Phil. Magazine," October, 1879) in 1879 with commutated direct currents, and by Deprez (" La Lumiere Electrique," December 8, 1883) in 1883 with alternating currents. It is scarcely conceivable that the application of these experiments would have escaped the eyes of the engineering world when the greater efficiency of polyphase alternators over single-phase alternators forced the former into general use. But that time had not come in 1888, and the motors described by Tesla, even if they had been commercially efficient structures, could not be operated on the circuits then existing.

Like Edison's three-wire system, the rotating field must have been obvious when changed conditions called for its application, but in 1888 it was not what was wanted. As Swinbourne said at the time ("Electrician," Vol. 21, p. 342): "The low efficiency is not at all the chief objection to the scheme. The whole arrangement is impracticable, as it demands special alternate-current generators and leads. Until Mr. Tesla can produce a motor which will work on alternate-current circuits as they are, and do that efficiently even with varying loads and without difficulty in starting, he can hardly be said to have solved the problem." The achievement of the Tesla and Ferraris publications was not the solution of a problem presented by existing conditions. They assumed nonexistent and, at that time, impracticable conditions, and then applied the obvious principle of the rotating field of Bailey and Deprez. Had not experience subsequently proved the polyphase generator more efficient than the single phase, the rotary field of Tesla and Ferraris, like that of Bailey and Deprez, would never have become of more than academic interest.

In time the polyphase generator did prove its superiority per se, and brought polyphase motors of different types with it into commercial use. But engineering to-day owes Tesla no more than it owes Ferraris, Deprez or Bailey, for Tesla never produced a commercially successful motor. As the demand for polyphase motors gradually came into existence he worked hard to produce a commercial motor, but it did not appear in the market. The motors of the so-called fundamental patents failed absolutely to meet commercial conditions. Though the later Tesla patents describe multitudinous modifications, Tesla himself, with practically unlimited means at his disposal, seems to have failed to produce a commercial self-starting motor for power purposes. Undoubtedly Tesla's theory of magnetic laws, as shown in some of his patents depending on so-called magnetic screening and on reducing iron losses by removing the iron, was an important factor in his failure. But other engineers equally failed to reduce those patents to practice, although on one occasion, according to the sworn testimony of a prominent engineer, $100,000 was offered if he would make the Tesla motor operate successfully.

Two widely different classes of alternating-current motors are in general commercial use to-day. They are known as synchronous motors and induction motors. The two differ radically in principle of design, in theory of operation, in method of manipulation, in the necessary accessory apparatus and in adaptability to different kinds of work.

The synchronous motor is simply an alternating-current generator with its function reversed. The same machine, with no change whatever, runs equally well as generator or motor. This is true of either single phase or polyphase. The polyphase generator is two or more single-phase machines wound on the same frame, and the same is true of the polyphase motor. When the electrical world had polyphase machines given it, and was told that alternating-current generators, like direct-current generators, were reversible, it knew all that was necessary for the successful operation of polyphase synchronous motors. And it had the machines (United States patent, No. 218,520, Gramme; "Electrician," October 28, 1882, p. 565; Gordon's dynamo electric machine) and it had the knowledge ("Jour. Soc. Tel. Eng." and "Electricity," Vol. 13, p. 496 and p. 515; "Electrician," November 15, 1884, p. 11; "Electric Illumination," by Dredge, London, 1882, Vol. 1, p. 69; "L'Electricien," August 1, 1884, p. 131; United States patent, No. 390,439) years before Tesla and Ferraris published the rotating field principle in 1888.

The synchronous motor, however, finds its applications in conditions of large power and continuous running. Those conditions are furnished by the great long-distance systems of power transmission of to-day, and it is only in such systems that the synchronous motor is or ever has been used. No such systems existed in 1888, and it was for this reason that though the reversibility of the alternating-current generator was known, it had never been utilized. The machine was there, but the conditions for its use were lacking. What was wanted then, and is wanted now, for general distribution and subdivision of power, was a small self-starting motor. This requirement is met by the "rotary field" or "induction" motor of to-day.

The man, in my opinion, to whom the induction motor is chiefly due is Dobrowolski. He was the first clearly to perceive the theory of its operation and the requirements in its design. To produce the maximum action of the alternating currents on the other member he perceived the necessity of a minimum magnetic air gap He gained the desired result, among other things, by imbedding the conductors in the iron, and his motor was a success. The first commercially successful induction motor of any size was the one built by him and exhibited at Frankfort in 1891. His designs were successfully copied in this country, and the induction motor of to-day became a fact.

After Tesla's apparent failure in motor production he turned to more promising fields. In 1891 he burst upon the electrical world with the first of a series of the most remarkable lectures ever delivered before a scientific audience. The experiments shown were fairly startling. Lamps and motors were operated on open circuit with a single-line wire. Lamps were made to burn brightly when short-circuited by a heavy copper bar, while exhausted tubes were brought to incandescence without any wire near them. Tubes were lighted by merely approaching them with the hand. Beautiful flames of varied appearance were made to leap from many objects, even from the hand of the lecturer himself.

Before the eyes of the startled spectators Tesla touched both terminals of a 200,000-volt transformer, with no more serious result than the production of the flames aforesaid. And throughout the lecture vague hints were offered of the tremendous possibilities exposed by the experiments—possibilities of obtaining unlimited light and power anywhere on the earth's surface, not by means of expensive wires from costly central stations, but by taking the energy directly from the earth itself or from the circumambient ether.

The public was astounded. Popular opinion, ever ready to ascribe the most impossible attributes to that vaguely understood force, electricity, hailed the lectures as disclosing a new era of wonders and Tesla as the last and greatest of electrical wizards. Even the eye of science was dazzled by Tesla's brilliant flames, and the most extravagant tributes were poured upon him. As stated in the London "Electrical Engineer": "No man in our age has achieved such a universal scientific reputation in a single stride as this gifted young electrical engineer."

It was asserted that similar effects to those shown by Tesla had previously been produced by Crookes, Hertz, Rayleigh, Spottiswood, Lodge, De La Rue, Kennedy and Thomson, some of those effects having been patented nine years before the first Tesla lecture (British patent, No. 4,752, Rankin Kennedy, 1882). But Tesla had made his experiments more spectacular by the use of higher voltages and higher frequencies, and the difference in degree passed for novelty in kind. It is true that the lectures abounded in fallacies and absurdities, as, for instance, Tesla's favorite theory of magnetic screening (" Inventions, Researches and Writings of Nikola Tesla," p. 185), his misconception of harmonics (Id., 187), his inexplicable statement regarding Arago's experiment (Id., 233), and even a gross misunderstanding of the fundamental law of physical science—the conservation of energy (Id., 147)—but all were overlooked or forgiven. Few, if any, measurements are recorded in the lectures; nor is there more than the feeblest attempt at even orderly sequence in the experiments, but spectacular sensationalism was accepted as a substitute for scientific methods. No attempt at any commercial adaptation of the experiments is described, but, instead, Tesla's vague hints at possibilities won him the reputation of prophet of the new era.

To-day, as we look back on those lectures of ten years ago and the developments since then, it is hard to understand the scientific enthusiasm Tesla aroused. Have any useful results ever come from those famous experiments? Instead of Tesla's high frequencies, the tendency has been steadily to lower frequencies. Instead of using static effects for power transmission, the chief problem on modern long-distance lines is to diminish those very effects. The electrostatic light is still a laboratory toy, while two wires and a filament are still used in commerce. Central stations still produce their power and distribute it through their mains. The prophecies of those lectures and articles are still unfulfilled, and their suggestions forgotten or disregarded. But ten years ago those who could see beyond the glamour of the Tesla tubes were few. Even then, however, there were some who regarded the lectures in the less spectacular light of science. The London " Electrical Review," in an editorial expressive of some bewilderment at the chaotic mass of experiments and of an inclination to suspend judgment until Tesla should have opportunity for further explanation through the press, calls attention to the fact that Tesla's work was not in a wholly unexplored field. (London " Electrical Review," Vol. 30, p. 184.) " The Electrician " at first called attention to the fact that the experiments were not new, but consisted " in repetitions of well-known effects on a large scale " (" Electrician," Vol. 28, p. 395), and later expressed itself conservatively as follows (" Electrician," Vol. 31, p. 139): " If a few quantitative determinations of current, voltage, or even of frequency, had been given in the lecture it would have had a definite scientific value. To reduce even one out of the 50 experiments to a complete reasearch would be worth all the other 49 brilliant and suggestive demonstrations." And " Industries " said (London " Electrical Review," Vol. 29, p. 193): " We have no desire to pick out weak points in such an interesting lecture, but we think that any one who read Mr. Tesla's articles must have had great difficulty in understanding his repeated idiomatic statements. Is it asking Mr. Tesla too much, holding the prominent position he does in the American electrical world, when we say we think if he omitted some of the confusing passages his lecture would be much better understood, and if he would keep ideas anent electro-magnetic theory of light, also Hertz and Dr. Lodge from his work, his experiments would be clearer, as well as more interesting. We hope Mr. Tesla is correct when he surmises that the future light may be produced by vacuum tubes, but we believe the subject has been thoroughly searched out ere this by many inventors without a result which has been very promising." In this connection, it might be mentioned that small acknowledgment of the work of Hertz or Lodge occurs in the lectures. The ambiguity referred to in the above quotation, and certainly existing in the lectures, has been passed over in this paper, as in Tesla's case a certain lack of facility in handling English may account for what in another would seem an attempt at mystification.

Had Tesla's labors ended with these lectures perhaps he would have received less criticism in these later days. They seemed to teem with brilliant possibilities. But the applause they had evoked seems to have resolved him to keep himself before the public at all hazards. In the succeeding years each new idea or fad in the electrical world was eagerly seized upon by him and made the pretext for rushing into print, at first in the technical papers, and later, as the engineering press began to regard his effusions askance, in the non-technical daily papers, the adoption of the latter medium being accompanied with increase in sensationalism. When X rays were holding the popular attention, he dabbled in them and published his results. (" Electrical World," Vol. 27, p. 343.) When the Wehnelt interrupter attracted the interest of scientists, Tesla immediately leaped into notice. As the London " Electrical Review " says (Vol. 44, p. 653): " Tesla lets himself out on the Wehnelt interruption in the ' Electrical Review ' (New York), March 15th. He invented this device two or three years ago. This belated publication in our contemporary would not, according to the generally accepted code, secure to Tesla the credit of being the inventor; but Tesla evidently does not regret this, since he considers there is not merit in the invention." And again (at p. 733): " Tesla has expressed a somewhat ungenerous contempt for the Wehnelt break, which has recently given such remarkable results in the hands of experimenters here and abroad. Its inferiority to Tesla's break appears to be known as yet only to Tesla; in simplicity, at least, it is certainly superior."

When the efforts of Marconi, Lodge and Slaby brought their first achievements in wireless telegraphy before the world Tesla had nothing but pity for their puerile efforts. When Marconi was ready to send a signal a few hundred miles, Tesla was ready (in the papers) to transmit thousands of horsepower the same distance. (" Century Magazine," June, 1900.) When Marconi was attempting to signal across the Atlantic, Tesla had already (in the papers) received a signal from Mars. (New York " Sun," Jan. 3, 1901). Before the enthusiasm over the Spanish War had had time to cool, Tesla had published a description of his torpedoes, which would revolutionize warfare. (New York " Sun," November 21, 1898.) The " Electrical Engineer " quotes the following from Tesla's signed article (at p. 514 of vol. 26): " We shall be able, availing ourselves of this advance, to send a projectile, at a much greater distance; it will not be limited in any way by weight or amount of explosive charge; we shall be able to submerge it at command, to arrest it in its flight and call it back, and to send it out again and explode it at will; and, more than this, it will never make a miss." The editorial comment follows: "When we are expected, wide awake and in our sober senses, to accept in silence such an utterance as that quoted above, or that which describes as 'a possibility' the operation of a distant torpedo boat by the mere exercise of the will, we refuse point blank, and we are willing to face the consequences." The significance of this comment lies in the fact that this paper had always been so ardent a supporter of Mr. Tesla that it had been said to have made him and his reputation, and from the pen of its editor-in-chief had come only four years previous the greatest tribute Tesla ever received. "Inventions, Researches and Writings of Nikola Tesla," by T. C. Martin.

It was of this torpedo boat invention that Tesla said ("Criterion," November 19, 1898): "Had I nothing else to show for a life-work, this would put the laurels of everlasting fame on my head." It was of this same invention that Prof. Brackett, of Princeton, said ("Electrical Engineer," Vol. 26, p. 491): "The shortest, most correct and most complete criticism which I can make in reference to this bold boast is that, what is new about it is useless, while that which is useful had all been discovered by other scientists long before Tesla made this startling announcement." It was of this invention that Prof. Dolbear, of Tufts College, said ("Electrical Engineer," Vol. 26, p. 491): "This last so-called invention of Nikola Tesla's is a very pretentious affair, and it is so incredible that the story is not to be believed until the work is actually done. The announcement is most amazing, and, coming as it does from Tesla, scientists are all the more chary about accepting it. During the last six years he has made so many startling announcements and has performed so few of his promises that he is getting to be like the man who called 'Wolf! wolf!' until no one listened to him. Mr. Tesla has failed so often before that there is no call to believe these things until he really does them."

Lack of time and space forbids more than a passing reference to the Tesla engine which was to revolutionize steam engineering; the "discovery" of the variation of capacity with elevation, which was to necessitate the rewriting of all electrical literature ("Electrical World," Vol. 37, p. 201); the torpedo boat, which was to be manipulated at the Paris Exposition from Tesla's laboratory at New York, but which failed to appear; the Tesla oscillator, which was to enable central stations to dispense with wires ("Century Magazine," June, 1900); the method of insulation by refrigeration, which was to give the highest efficiency to transmission with wires ("Western Electrician," Vol. 27, p. 122); and even the message actually received from Mars (New York "Sun," January 3, 1901) must be passed by with merely the comment made by Prof. Fessenden ("Electrical World," Vol. 37, p. 165) that "only the crassest ignorance could attribute any such origin" to the so-called signals.

From the mass of imaginative literature that has recently issued from Tesla's ever-ready pen a single one is here selected for comment. It is chosen both because it includes a large number of Tesla's vagaries, and also because its publication in a magazine of some standing drew more attention to it than was bestowed on others appearing in the more sensational daily press.

"In the 'Century Magazine' for

June, 1900, Mr. Tesla printed a long article, superbly illustrated with cuts that had little or nothing to do with his subject, which dealt with a few electrical matters and also with philosophies and social problems, upon which he freely expressed a jumble of trivial, ignorant, pretentious and erroneous opinions." (" Popular Science Monthly," Vol. 58, p. 437.) This article attracted widespread attention, and if Tesla in truth experiences a feeling of satisfaction at adverse criticism, as he once stated in the New York " Sun," he must have enjoyed keen ecstacies on reading the comments it evoked, as the above quotation would indicate. Nor did the " Century " itself escape criticism. In publishing such pseudo-scientific productions such magazines " descend to a footing with the Sunday newspaper. They evidently do not know science from rubbish, and apparently seldom make any effort to find out the difference." (" Popular Science Monthly," July, 1900.) A brief review of the article will assist to an appreciation of the justice of the criticisms, and, perhaps, to a truer estimate of Tesla's character and the value to be put upon his work than could otherwise be obtained.

The problem treated is that of humanity as a mass acted on by forces, one tending to acceleration, the other to retardation. The three methods of increasing the energy are the increase of the mass, the diminution of the retarding force, and the increase of the force making for progress. The treatment of the first method need not be considered here. It consists merely in the assertion of well-known sociological principles. It is the second method that introduces the first novel element in this remarkable paper. War is justly considered an important factor in the retarding force, and the means of its elimination are unique. Battles will no longer be waged by human beings, but, instead, by machines, by Tesla's " telautomatons."

Rival fleets of these beneficent Frankensteins will clash in mid-ocean for the determination of maritime supremacy, their maneuvers being controlled from physicists' laboratories on shore. These long-distance weapons, the harbingers of universal peace, are already perfected. Another more wonderful type is on its way. (Quoting from the " Century " article): " An automaton may be contrived which will have its ' own mind,' and by this I mean that it will be able, independent of any operator, left entirely to itself, to perform, in response to external influences affecting its sensitive organs, a great variety of acts and operations as if it had intelligence. It will be able to follow a course laid out or to obey orders given far in advance. It will be capable of distinguishing between what it ought and what it ought not to do, and of making experiences, or, otherwise stated, of recording impressions which will definitely affect its subsequent actions. In fact, I have already conceived such a plan." Truly, Tesla's science is stranger than fiction. This noble scheme for universal peace must be passed by with a single quoted comment (" Popular Science Monthly," July, 1900): " Inasmuch as the interest in this telautomatic warfare is to be purely aesthetic, it would seem as if international bull fights or kite flying, or spelling matches, or potato races, might do as well, and have the added advantage of leaving Mr. Tesla's expectations free to wander among the following prospective discoveries."

The methods of increasing the accelerating force comprise the third and largest division of the " Century " article This section is introduced by the wise but trite statement that all energy is derived from the sun. Three ways of manipulating this energy efficiently are suggested—the cold coal battery, direct utilization of the energy of the ether, and transmission of power through the ether. The first method is introduced by a digression on the value of iron and the wastefulness of its present production, with incidental reference to a new method of manufacture perfected by Tesla in which water is the fuel, having previously been decomposed electrolytically. This method of reduction is stated to be " cheaper than by any of the adopted methods." The digression is continued by a reference to aluminum and its prospective value to mankind. Then electric transmission is considered and the following remarkable statement appears: " Steamers and trains are still being propelled by the direct application of steam power to shafts or axles. A much greater percentage of the heat energy of the fuel could be transformed in motive energy by using, in place of the adopted marine engines and locomotives, dynamos driven by specially designed high-pressure steam or gas engines and by utilizing the electricity generated for the propulsion. A gain of 50 to 100 per cent. in the effective energy derived from the coal could be secured in this manner. It is difficult to understand why a fact so plain and obvious is not receiving more attention from engineers. In ocean steamers such an improvement would be particularly desirable, as it would do away with noise and increase materially the speed and the carrying capacity of the liners." This difficulty of Tesla's must have been cleared away by a paper of Prof. Durand's (" Marine Engineering," July, 1900), who points out that in the case of a liner of 25,000 horse power, Tesla's scheme would result in loss of about one-third of carrying capacity, besides a loss of about 2,500 horse power due to two transformations of energy, hence a loss in speed of one-half to three-quarters of a knot. As Prof. Durand remarks, " The increase of carrying capacity referred to at the close of the quotation would be, therefore, of a character not likely to commend itself to the stockholders or board of directors."

The cold coal battery itself receives scant notice. Apparently it is one of the few things Tesla has not yet perfected.

The treatment of the method of deriving energy direct from the ether contains numerous suggestions. Brief reference is made to the windmill and the solar engine. Then two perpetual motion possibilities are described. The first is a disc kept in motion by a gravity screen. A critic regrets ("Popular Science Mo.," July, 1900) that " Into further particulars concerning the nature of such a screen Mr. Tesla does not enter, though it would seem a matter well fitted to engage his peculiar gifts." The second is a perpetual heat engine, regarding which the critic just quoted says: " We should thus employ ' an ideal way of obtaining motor power ' and incidentally rebuke the narrow minded physics of Carnot and Lord Kelvin." This section ends with a mention of the Tesla mechanical oscillator and a reference to liquid air.

The third and last method, that of utilizing the ether as a bus bar, is stated to find greatest favor in the author's eyes. Mention is made of his experiments with one wire and with none, with wobbling the earth's charge and with electrifying the upper strata of the atmosphere. The secret of tuning for wireless transmission is revealed and the errors of the experiments of Hertz pointed out. The possibility of signaling to Mars is asserted, and the facts of power transmission are stated as follows: "The experiments have shown conclusively that, with two terminals maintained at an elevation of not more than 30,000 to 35,000 feet above the sea level, and with an electric pressure of 15,000,000 to 20,000,000 volts, the energy of thousands of horse power can be transmitted over distances which may be hundreds and, if necessary, thousands of miles." No data as to methods of ballooning or of supporting wires at this elevation are given. Instead, the article closes with a quotation from Goethe. This quotation, with its reference to fulfilment, furnishes a most strikingly complete and sarcastic, though evidently unconscious, comment on the whole ludicrous production.

A perusal of the article forces one to coincide with the verdict of "Marine Engineering," whose editor describes it ("Marine Engineering," July, 1900) as the "handiwork of a cerebrose individual—a bombastical genius who has illumined unknown fields of imaginative science with his intellectual searchlight, and is willing to permit the gaping world of ignorance or complaisance to peep in and wonder, the credulous editor drawing the curtain. This dazzling contribution to modern unscientific research reads like nothing so much as an essay on Christian Science, so profound is it in the ambiguous nothingness whereby it leads through the intricacies of incoherency into the climax of absolute assininity."

Enough has been given to indicate the reason for the standing that is Tesla's today in the scientific world. Not even the brilliancy of suggestion and experiment contained in his early work, not even the persistent efforts of powerful friends, moved by their commercial interests to magnify and exalt the value of his patented inventions, could avert the discredit to his reputation as a scientist brought upon himself by his wild struggles for notoriety He has been condemned by his own extravagant boasts, never followed by the realization of their claims and often revealing a total misunderstanding of the very elements of physical laws.

Tesla is still a young man, and those whose sympathetic expectation was aroused by his early work still hope that he will turn from the gaudy notoriety of the Sunday newspaper, and by conscientious work give at last one complete useful invention that may be honestly set to his credit, and that may make its influence felt on the progress of engineering science.